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A Computer Program for the Design of Roads, Streets, and Open Storage Areas, Elastic Layered Method—LEDROAD

by Yu T. Chou
Geotechnical Laboratory

WES

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Prepared for Headquarters, U.S. Army Corps of Engineers

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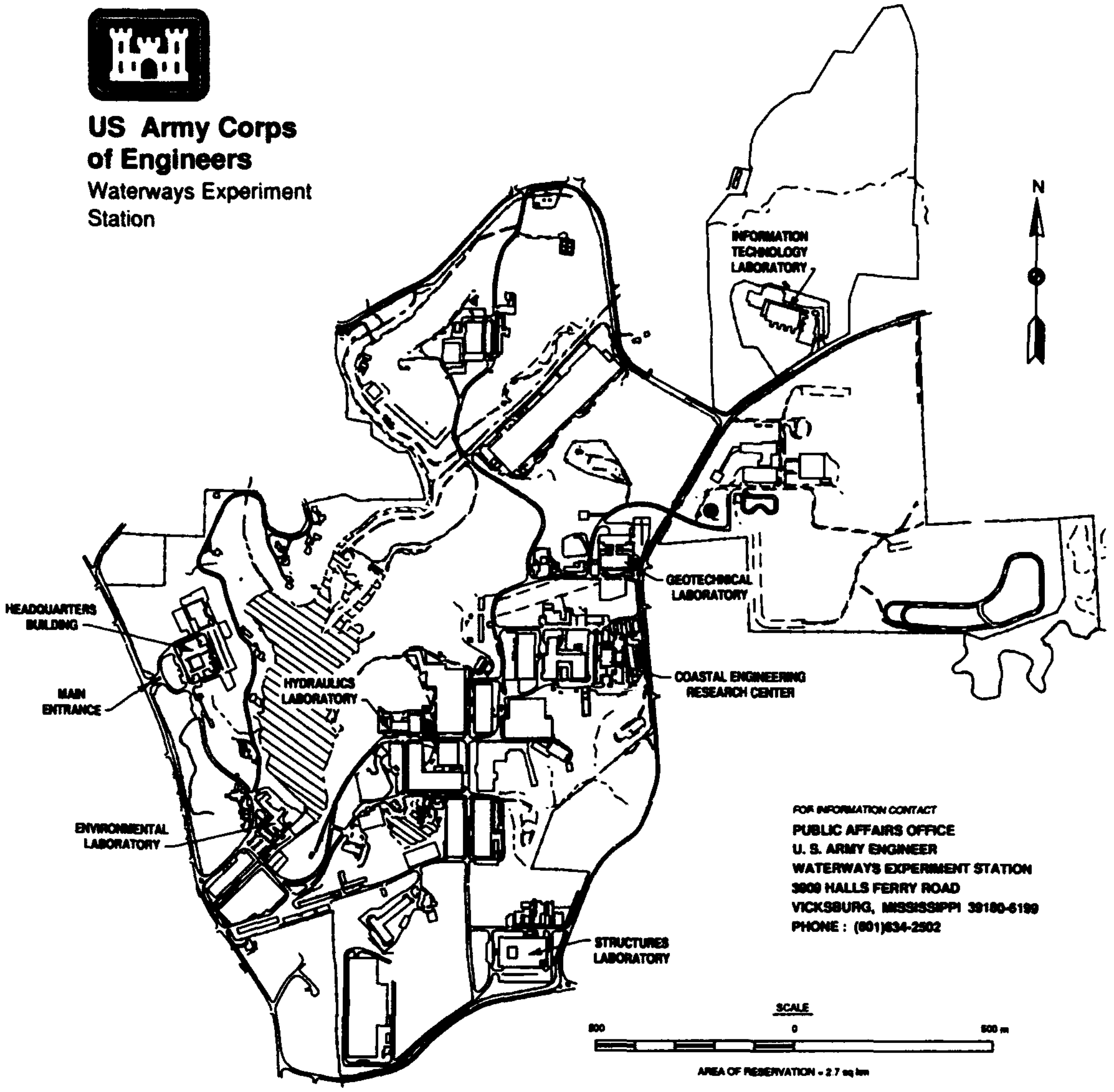

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Contents

Preface

The work reported herein was developed under the Headquarters, U.S. Army Corps of Engineers PCASE program. Mr. Greg Hughes, U.S. Army Corps of Engineers, was the Technical Monitor.

The study was conducted from June 1991 to February 1992 at the U.S. Army Engineer Waterways Experiment Station (WES), Geotechnical Laboratory (GL), by Dr. Yu T. Chou, Pavement Systems Division (PSD). The work was performed under the general supervision of Dr. W. F. Marcuson III, Director, GL, and direct supervision of Dr. George Hammit II, Chief, PSD, and Dr. Al Bush, Chief, Criteria and Development Branch. This report was written by Dr. Chou.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
kips (force)	4.448222	kilonewtons
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
square inches	6.4516	square centimeters
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

Background

An engineering technical manual entitled "Pavement Design for Roads, Streets, and Open Storage Areas, Elastic Layered Method" has been prepared which uses an elastic layered method for the design of military roads, streets, and open storage areas.[1] A user-friendly computer program, LEDROAD (Layered Elastic Design for Roads), was developed to carry out the design work.

Purpose and Scope

The purpose of this report is to provide users with the necessary information for running the LEDROAD computer program. The report contains the programming logic, computer system requirements, user instructions, and the input and output of an example problem. The design pavements include plain concrete, reinforced concrete, conventional flexible pavements, all bituminous concrete pavements, and flexible pavement with stabilized layers.

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[1] Headquarters, Department of the Army. "Pavement design for roads, streets, and open storage areas," TM 5-822-13/AFM 32-8007, Vol 1, Washington, DC.

2 Program Logic and System Requirements

Program Logic

LEDROAD is revised from LED, the layered elastic computer program for airfield pavement design developed at the U.S. Army Engineer Waterways Experiment Station (WES). The program has six main parts (Figure 1), which are presented below.

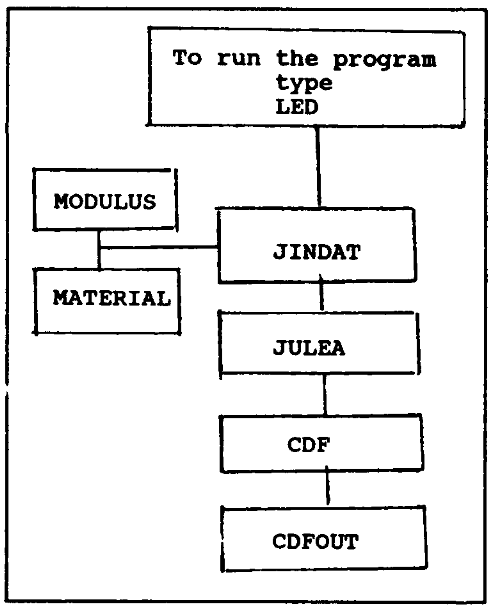

Figure 1. Flow chart of LEDROAD program

JINDAT. Pavement structure data files (i.e., trial pavement sections for design) and load data files should first be established. This can be accomplished by typing in JINDAT at the DOS prompt and following the instructions shown on the screen. For a pavement structure file, three or four trial pavement sections are suggested for estimating pavement damage. A proper thickness is then selected at a damage value of one. For instance, for a concrete pavement designed to support passenger cars and military trucks, trial thicknesses of 4, 7, 11, and 15 in.[1] may be used. The damage versus thickness curves are plotted in CDFOUT (from which the design thickness is determined at a damage value of one).

JULEA. The stresses and strains in the pavement structures under the design axle loads are computed in JULEA based on the Burmister layered

[1] A table of factors for converting non-SI units of measurement to SI is presented on page v.

elastic solution. This can be accomplished by typing in JULEA at the DOS prompt and following the instructions shown on the screen.

CDF. Pavement damage values for all trial pavements are computed based on the stresses and strains computed in JULEA and the associated failure criteria. For rigid pavements, the criterion is based on the tensile stress at the bottom of the slab. For flexible and all-bituminous concrete pavements, the criteria are based on the tensile strain at the bottom of the asphaltic concrete layer and the vertical strain at the subgrade surface. Development of the associated failure criteria is presented in Chou (1989, 1992).[1, 2] The damage is computed using Miner's theory and is accumulated for each seasonal variation.

CDFOUT. CDFOUT is designed for viewing computed damage values and stresses and strains. This is accomplished by typing in CDFOUT at the DOS prompt and following the instructions shown on the screen. When viewing the data, make sure to check pavement and axle information to ensure they are correct and not data from a previous run.

MODULUS. MODULUS determines moduli of granular layers based on the modulus of the underlying layer. This program was developed at WES and can be activated by typing in MODULUS at the DOS prompt and following the instructions shown on the screen. The required inputs are the thicknesses of granular layers and the subgrade modulus value.

MATERIAL. MATERIAL is a program that provides information and modulus values of pavement materials. The program is activated by typing in MATERIAL and following the instructions shown on the screen.

System Requirements

The computer program was compiled using the Microsoft FORTRAN 5.0 compiler and was designed to operate on an IBM or compatible machine under the DOS 3.0 operating system or a later system. The graphics libraries and extensions to the standard FORTRAN included with this compiler were implemented in this program. Although not required, an IBM AT class computer or better with a math co-processor and 640 KB of main memory is recommended.

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[1] Yu T. Chou. (1989). "Development of failure criteria of rigid pavement thickness requirements for military roads and streets, elastic layered method," Miscellaneous Paper GL-89-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

[2] Yu T. Chou. (1992). "Development of failure criteria of flexible pavement thickness requirements for militiary roads and streets, elastic layered method," Miscellaneous Paper GL-92-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

3 User's Instructions

Input Data Computer Program, JINDAT

Data are input in JINDAT in which the load files *.LOA, structure (or pavement) files *.STR, ACDAM.DAT file, SIGMA.DAT file, and *.COV files are generated. The load file name and the structure file are automatically fixed with extensions .LOA and .STR, respectively. The *.LOA and *.STR files are used in computing stresses and strains in JULEA, and the file names are saved in LAST.FIL. The AC.DAT file contains axle data and should not be altered unless a change is necessary. The top part of AC.DAT has information used in JULEA, and the remaining part has information used in CDF. The ACDAM.DAT file contains data of the selected axles for computing damage in CDF. The SIGMA.DAT and *.COV files are used in CDF in which SIGMA.DAT reads design axle load data and standard deviations. The *.COV file computes coverage per pass ratios of selected axles. SIGMA.DAT and *.DAT are text files which may be viewed and manually modified with text editors.

When pavement data are input, the following features should be noted:

a. *Modulus values.* Information on modulus values of pavement layer materials can be obtained from the program MATERIAL. The moduli of granular materials may be determined using the program MODULUS.

b. *Seasonal variations.* Since asphaltic concrete moduli vary with ambient temperature, pavement damage should be computed at seasons of near-same temperature. For instance, if the pavements are designed for five seasons, the number of seasonal variation is 5. Note that the number of seasonal variations is the same for all trial pavement structures. If a series of four trial sections has thicknesses of 8, 12, 16, 20 in. and the number of seasons to account for modulus variation is 3, the number of pavement structures is $3 \times 4 = 12$.

c. *Depth value.* In order to compute stresses and strains along an interface, the depth value should indicate if the location is at the bottom of the layer above the interface or at the top of the layer beneath the interface. The depth value is negative if the computational location is at the bottom of the layer above the interface and is positive if it is at the top of the layer beneath the interface. For instance, if a three-layer pavement has an 8-in. Portland cement concrete (PCC) layer under a 6-in. asphalt concrete (AC) overlay, a depth value of -14 in. indicates a location at the bottom of the PCC layer, and a depth value of 14 in. indicates the location is at the subgrade surface. This is important when the contents of LOAD.DIR and STRC.DIR files are to be manually changed.

d. *Interface conditions*. Total adhesion is used for all interfaces in flexible pavements, including all-bituminous concrete (ABC). It is to be noted that the vertical strains at the subgrade surface in an ABC pavement are much greater when the asphalt layer is fully bonded to the subgrade than if they are not bonded. For concrete slabs, total or partial slip may be used.

For load files, the design vehicles are divided into axle groups input to JULEA for computation of stresses and strains. A passenger car has two axles, which are both single axle, single wheels. A medium weight truck usually has two axle loads: the front is single axle, single wheels, and the rear is either tandem axle, dual wheels, or single axle, dual wheels. An 18-wheeler has three axles: the front is single axle, single wheels, and the middle and back axles are tandem axle, dual wheels. For track vehicles, such as military tanks, each track load has been converted into eight circular loads and is considered as one axle load. Table 1 shows 19 axle loads based on the wheel configuration and weight category, which covers a wide range of loads for design of miliary roads and streets. The background of the group classification is presented in Technical Report No. 3-582.[1]

For example, if the design is for the following traffic:

10,000 passes of passenger cars, 1.5 kips for each axle
5,000 passes of a truck load, with a 9-kip single axle, single wheels, in the front, and a 32-kip tandem axle, dual wheel load in the rear
1,000 passes of a 60-ton M1 tank

The design axle loads, according to Table 1, will be:

20,000 passes of No. 1 axle load (2 × 10,000)
5,000 passes of No. 2 axle load (5,000)
5,000 passes of No. 10 axle load (5,000)
1,000 passes of No. 19 axle load (1,000)
(Note: Axle numbers refer to the axles in Table 1.)

[1] U.S. Army Engineer Waterways Experiment Station. (1961). "Revised method of thickness design for flexible highway pavements at military installations," Technical Report No. 3-582, Vicksburg, MS.

Table 1
Design Load Axles

Configuration	Load Range, kips
Passenger cars, trucks, buses, etc.	
Pneumatic tires	
1. Single axle, single wheels	0- 5
2. Single axle, single wheels	5-10
3. Single axle, dual wheels	0-10
4. Single axle, dual wheels	10-20
5. Single axle, dual wheels	20-30
6. Tandem axle, single wheels	0-10
7 Tandem axle, single wheels	10-15
8. Tandem axle, dual wheels	10-15
9. Tandem axle, dual wheels	15-20
10. Tandem axle, dual wheels	20-50
Forklift truck	
Pneumatic tires	
11.Single axle, dual wheels	10-35
Solid rubber tires	
12.Single axle, single wheels	0- 5
13.Single axle, single wheels	5-10
14.Single axle, single wheels	10-20
Tracked vehicles	
15.solid rubber grousers	0-20
16.solid rubber grousers	20-35
17.solid rubber grousers	35-50
18.solid rubber grousers	50-70
19.solid rubber grousers	70-120

Stress and Strain Computation Program, JULEA

The number of layers in a pavement structure is limited to 16 in JULEA. Computations are not made at depths less than 0.2 radii of the loading circular area. The load and structure files can be copied, manually modified, and renamed to expedite the input process, but the file name has to be added to the list in LOAD.DIR or STRC.DIR files. These files keep a record of the load and structure data files created in JINDAT. Note the total number of files has to be changed accordingly in LOAD.DIR or STRC.DIR. Care should be exercised when manually modifying the load and structure files so as not to change the file format; otherwise, run-time error will occur in running JULEA and CDF. In this case, it is best to recreate the structure and load files. An output file name has to be provided for JULEA. File names with extension OUT (such as xxxx.OUT) are recommended for easy retrieval. When JULEA is run, DAMINR.DAT (for rigid pavement), DAMINF.DAT (for flexible pavement), and DAMTMP.DAT are created. These three files contain data of selected axle loads and computed maximum stresses and strains from which pavement damage is computed.

When JULEA is run, the user selects the load and structure files from the listings shown on the screen (LOAD.DIR and STRC.DIR files), and the user should be careful to select the correct files. If the load and structure data files have not been created, they should be created by first running JINDAT.

Damage Computation Program, CDF

It is important for the user to remember that it is *mandatory* to first run JINDAT and JULEA before running CDF. Damage is computed based on the selected axle loads listed in SIGMA.DAT, which was updated when JINDAT was run. When CDF is run without first going through JINDAT, the damage will be computed based on the selected axles listed in SIGMA.DAT of the previous JINDAT run, and the axles may not be the ones intended in the current run.

Since a moving vehicle wanders across the pavement, (i.e., the center of the vehicle does not follow the center of the traffic lane all the time), a standard deviation of wander is used for each axle group. This standard deviation is important in computing damage as it affects the operation per coverage ratio. In general, the greater the standard deviation of the axle load, the lesser the pavement damage. It should also be pointed out that the operation per coverage ratios calculated by computer in the LEDROAD can be different from those computed by using calculators in Technical Report 3-582.

It is extremely important to be certain that the pavement and traffic information in computing the damage is correct. Data from the previous run are still in the memory. To ensure the correctness, CDF should be run right after computing JINDAT and JULEA. Traffic data shown on the screen are left from the previous run and should always be changed for data of the present run.

Output Program, CDFOUT

Output can be viewed on the screen and printed in running CDFOUT. CDFFLEX.OUT is the output file for flexible pavement, and CDFRIGID.OUT is the output file for rigid pavement. It is again extremely important to be certain that the pavement and traffic information are correct. Data from the previous run are still in the memory.

4 Design Example

This chapter presents the results of an example problem run which the user may use to check his own computer results to ensure the correctness of the computer run.

a. Traffic:

800,000 passes of No. 1 axle, 1,500 lb
900,000 passes of No. 4 axle, 18,000 lb
900,000 passes of No. 10 axle, 32,000 lb

b. Pavements: Three trial concrete pavements are to be used. The following tabulation shows the layer material properties:

Layer thickness: 4, 6, 8 in.
Modulus of elasticity of PCC: 4,000,000 psi
Poisson's ratio of PCC: 0.2
Flexural strength of PCC: 675 psi
Modulus of elasticity of the subgrade: 6,000 psi
Poisson's ratio of the subgrade: 0.4
Interface condition under the concrete slab: 100,000 (total slip case)

After JINDAT is run, load file EXAMPLE.LOA and structure file EXAMPLE.STR are created as shown in Tables 2 and 3, respectively. EXAMPLE.LOA contains input information for the three selected axle loads and the locations of evaluation points for computing stresses and strains from which the maximum values are determined. EXAMPLE.STR contains input information for the three trial pavements. The two files are read in JULEA for computing stresses, strains, and deflections. The complete output of JULEA is stored in EXAMPLE.OUT which can be viewed on screen or printed out on hard copies. Information on the selected axle loads is stored in the ACDAM.DAT file as shown in Table 4. ACDAM.DAT is read in CDF for computing pavement damage. The maximum stresses and strains in EXAMPLE.OUT are stored in the file DAMTMP.DAT which is used in CDF. The DAMTMP.DAT file of this example run is presented in Table 5.

Table 2
A Load Data File for JINDAT, EXAMPLE.LOA

```
 LOAD Data File
 Job Title
EXAMPLE PROBLEM
 No. of Axle
 3
 Axle Identification #  1
01:   0-5
 Gross Load
     1500.00
 Fraction of Gross Load on the Axle to be analyzed
  1.000
 No. of Tires
 2
 Tire   Radius   Cont.Area   Cont.Press.   Tire Load   X-coord.   Y-coord.
 No.     (in)    (sq.in)      (psi)        (pounds)     (in)       (in)
 --------------------------------------------------------------------------
  1      1.85     10.71        70.00        750.00     -31.00       .00
  2      1.85     10.71        70.00        750.00      31.00       .00
 No. of Evaluation Points ( X,Y Sets )
 1
 Point No.       X-coord.          Y-coord.
                  ( in )            ( in )
 ----------------------------------------
     1           -31.00              .00
 Axle Identification #  2
04: 10-20
 Gross Load
    18000.00
 Fraction of Gross Load on the Gear to be analyzed
  1.000
 No. of Tires
 4
 Tire   Radius   Cont.Area   Cont.Press.   Tire Load   X-coord.   Y-coord.
 No.     (in)    (sq.in)      (psi)        (pounds)     (in)       (in)
 --------------------------------------------------------------------------
  1      4.52     64.29        70.00       4500.00     -42.75       .00
  2      4.52     64.29        70.00       4500.00     -29.25       .00
  3      4.52     64.29        70.00       4500.00      29.25       .00
  4      4.52     64.29        70.00       4500.00      42.75       .00
 No. of Evaluation Points ( X,Y Sets )
 3
 Point No.       X-coord.          Y-coord.
                  ( in )            ( in )
 ----------------------------------------
     1            29.25              .00
     2            32.63              .00
     3            36.00              .00
 Axle Identification #  3
10: 20-50
 Gross Load
    32000.00
 Fraction of Gross Load on the Gear to be analyzed
  1.000
 No. of Tires
 8
 Tire   Radius   Cont.Area   Cont.Press.   Tire Load   X-coord.   Y-coord.
 No.     (in)    (sq.in)      (psi)        (pounds)     (in)       (in)
 --------------------------------------------------------------------------
  1      4.26     57.14        70.00       4000.00     -42.75       .00
  2      4.26     57.14        70.00       4000.00     -29.25       .00
```

(Continued)

Table 2 (Concluded)

3	4.26	57.14	70.00	4000.00	29.25	.00
4	4.26	57.14	70.00	4000.00	42.75	.00
5	4.26	57.14	70.00	4000.00	-42.75	48.00
6	4.26	57.14	70.00	4000.00	-29.25	48.00
7	4.26	57.14	70.00	4000.00	29.25	48.00
8	4.26	57.14	70.00	4000.00	42.75	48.00

No. of Evaluation Points (X,Y Sets)
6

Point No.	X-coord. (in)	Y-coord. (in)
1	29.25	.00
2	32.63	.00
3	36.00	.00
4	36.00	24.00
5	32.63	12.00
6	36.00	12.00

Table 3
A Structural Data File for JINDAT, EXAMPLE.STR

```
 STRUCTURE Data File
 Job Title
EXAMPLE PROBLEM
 Number of Pavements
 3
 Number Thicknesses & Moduli Variations
          3            1
 Pavement Description
Rigid Pavement
 Slab Flexural Strength (only for rigid pavements)
        675.00000000
 No. of Layers
   2
   Layer       Thicknesses     Modulus of   Poisson's   Interface
   Number        ( in )        Elasticity    Ratio      Condition      Layer Code
                                 ( psi )
   -------------------------------------------------------------
     1             4.00        4000000.00        .200                       0
                                                          100000.00
     2                            6000.00        .400                       0
 No. of Depths
   1
  Depth No.        Depth (in)
  ---------------------------
     1         -4.00000000
 Pavement Description
Rigid Pavement
 Slab Flexural Strength (only for rigid pavements)
        675.00000000
 No. of Layers
   2
   Layer       Thicknesses     Modulus of   Poisson's   Interface
   Number        ( in )        Elasticity    Ratio      Condition      Layer Code
                                 ( psi )
   -------------------------------------------------------------
     1             6.00        4000000.00        .200                       0
                                                          100000.00
     2                            6000.00        .400                       0
 No. of Depths
   1
  Depth No.        Depth (in)
  ---------------------------
     1         -6.00000000
 Pavement Description
Rigid Pavement
 Slab Flexural Strength (only for rigid pavements)
        675.00000000
 No. of Layers
   2
   Layer       Thicknesses     Modulus of   Poisson's   Interface
   Number        ( in )        Elasticity    Ratio      Condition      Layer Code
                                 ( psi )
   -------------------------------------------------------------
     1             8.00        4000000.00        .200                       0
                                                          100000.00
     2                            6000.00        .400                       0
 No. of Depths
   1
  Depth No.        Depth (in)
  ---------------------------
      1         -8.00000000
```

Table 4
ADCAM.DAT File Created in JINDAT

```
01:   0-5
N
            2
     5.331317        8.530107
            2
    62.000000    0.000000E+00    0.000000E+00    0.000000E+00
   -31.000000
    31.000000
04: 10-20
N
            4
     7.539621       12.063390
            3
    13.500000       56.500000    0.000000E+00    0.000000E+00
   -41.750000
   -28.250000
    28.250000
    41.750000
10: 20-50
N
            4
     8.429552       13.487280
            3
    13.500000       58.500000    0.000000E+00    1.250000E-01
   -42.750000
   -29.250000
    29.250000
    42.750000
```

Table 5
DADTMP.DAT File Created in JULEA

```
 Number of Pavements
           3
 Number of Thickness & Modulii Variations, ACs and RConcrete
  3  1  3 675.00
           Gross   Layer              E        Tensile
 AC        Load     No.   Depth    Modulus     Stress
01:   0-5    1500.   1     4.0   4.0000E+06  -7.8397E+01
04: 10-20   18000.   1     4.0   4.0000E+06  -4.8188E+02
10: 20-50   32000.   1     4.0   4.0000E+06  -3.8968E+02
           Gross   Layer              E        Tensile
 AC        Load     No.   Depth    Modulus     Stress
01:   0-5    1500.   1     6.0   4.0000E+06  -3.8278E+01
04: 10-20   18000.   1     6.0   4.0000E+06  -2.8135E+02
10: 20-50   32000.   1     6.0   4.0000E+06  -2.3424E+02
           Gross   Layer              E        Tensile
 AC        Load     No.   Depth    Modulus     Stress
01:   0-5    1500.   1     8.0   4.0000E+06  -2.2890E+01
04: 10-20   18000.   1     8.0   4.0000E+06  -1.8921E+02
10: 20-50   32000.   1     8.0   4.0000E+06  -1.6711E+02
```

After CDF is run, output can be viewed, plotted on the screen, or printed out on hard copies in CDFOUT. The maximum damage for the three trial concrete slabs is shown in Table 6. The damage computed is the cumulative damages of three selected axle loads. Figure 2 shows the plot of concrete thickness versus coverage curve from which the design thickness is determined.

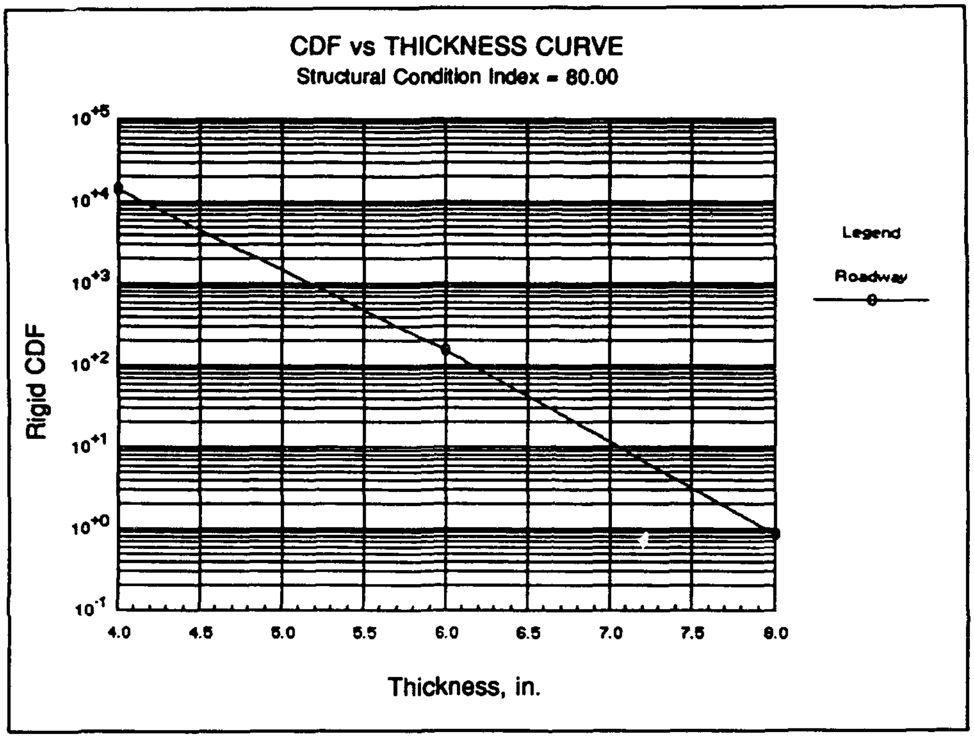

Figure 2. Pavement damage versus concrete thickness

5 Recommendations

Computer program LEDROAD can be used for the design of military roads, streets, and open storage areas. Computer program JULEA can be used to compute pavement stresses and strains. Although the programs are user-friendly, this report will be beneficial for users when questions arise. To ensure the correctness of the computer run, first-time users should run a problem using the input data provided in the example run and check the computer results with those provided in Tables 2-5.

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13. ABSTRACT *(Maximum 200 words)*

A user-friendly computer program, LEDROAD, is presented for the design of roads, streets, and open storage areas using the elastic layered method. The program is designed to operate on an IBM or compatible machine under the DOS 3.0 operating system or a later system. The report provides users with necessary information for running LEDROAD, including the programming logic, computer system requirements, user instructions, and the input and output of an example problem run. LEDROAD can be used to design pavements consisting of plain concrete, reinforced concrete, conventional flexible pavements, all-bituminous concrete pavements, and flexible pavement with stabilized layers.

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